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SOUNDS PRODUCED BY WOOD BORING MARINE ANIMALS AND ATTEMPTS TO DETECT THESE ANIMALS IN WATERFRONT STRUCTURES USING PASSIVE SONIC TECHNIQUES

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Wood boring organisms such as shipworms and gribbles make characteristic sounds as they actively bore into wood. In the laboratory these sounds isolated from ambient noise have been recorded and analyzed. In habor areas, infested piles and seawalls are usually covered with fouling growth such as barnacles, and the noise created by feeding barnacles and other foulers make it impossible to detect the soft low intensity sounds of wood borers.

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SOUNDS PRODUCED BY WOOD BORING MARINE ANIMALS AND ATTEMPTS TO DETECT THESE ANIMALS IN WATERFRONT STRUCTURES USING PASSIVE SONIC TECHNIQUES

by

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Introduction

Damage caused by marine animals to wooden harbor structures exposed to sea water often goes undetected until the damage is so extensive the structures fail. This is particularly true of wooden pilings and sea walls or bulkheads when they are infected with shipworms such as *Bankia* or *Teredo*, for these borers have very small entrance holes and the entire interior of a piling might be destroyed with little evidence of damage from the outside. The boring activities of the wood gribbles in the genus *Limnoria* are often more noticeable and easily detected, but when a wooden piling is covered with a growth of fouling organisms even *Limnoria* damage might go undetected.

Harbor maintenance personnel usually examine submerged wooden structures using shallow water diving gear. It is often easy to detect gribble damage if the surface of the wood is free of fouling, but it is next to impossible to detect the delicate siphons protruding from the burrows of shipworms when visually examining the piling while diving. There is a need, therefore, for some mechanism or technique that would permit accurate detection of marine wood borers *in situ* without making extensive test drill holes in the wood. One technique might be to employ passive listening in the hope of detecting a unique set of sounds that would betray the presence of wood borers that could not be seen visually from the outside.

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Major Types of Wood Boring Animals

In the coastal waters of the United States wood boring animals are primarily of two kinds, the shipworms and gribbles. Shipworms are bivalve molluscs. They are specialized clams that instead of digging burrows in sediments such as sand or mud have evolved mechanisms for boring into wood. They form burrows primarily for protection from predators. Like most clams they have a pelagic larval stage in the plankton and when they settle to the bottom they look like typical young clams. Settled larvae of the California shipworm Bankia setacea are 0.25 mm long. They must find wood to bore into or they perish. When a juvenile shipworm contacts a water soaked timber on the bottom, or a piling in a harbor, it immediately digs into the wood by rocking its shell back and forward against the wood. At first it digs straight down but soon turns and burrows with the grain of the wood eventually forming a long cylindrical tunnel 2 cm or more in diameter and 50 cm or more long. The animal becomes elongate and worm-like, for it fills the entire burrow. At the entrance hole the animal extends out into the water two delicate tube-like siphons, one for bringing sea water into the burrow, and one for exhaling it. At the forward end of the animal, next to the blind end of the elongated tunnel, is the small sub-spherical shell made up of two valves as in all clams. It is the shell that is the tool used in excavating the wood and forming the smooth cylindrical tunnel. The excavated wood is passed through the intestinal tract of the animal where some of it is digested and used for food, while most of the wood passes out of the animal and burrow by way of the exhalent siphon. The inhalent siphon brings in fresh sea water containing oxygen and the planktonic organisms upon which the shipworm depends for most of its food.

A shipworm bores into wood by clinging to the blind end of the tunnel with its rounded, sucker-like foot, and pressing the bivalved shell against the wood. The anterior part of each shell valve is toothed and serrated, and this part of each valve is rasped against the wood by alternate contractions of anterior and posterior adductor muscles which rock the shell valves back and forth. The effective rasping stroke which removes wood fibers from the end of the borrow results from contraction of the powerful posterior adductor muscle. The anterior adductor muscle then moves the two valves into position for another rasping stroke. As excavation of the wood proceeds, the animal slowly rotates in the burrow and the tunnel formed is perfectly cylindrical. In Monterey Bay the shipworm _Bankia setacea_ can bore into pine or fir at rates of up to 7.5 cm per month (Haderlie & Mellor, 1973).

Gribbles of the genus _Limnoria_, on the other hand, are crustaceans related to the sowbugs or pillbugs found on land. They are small white animals about 4.5 mm long with segmented bodies. They have seven pairs of short legs each with a claw for clinging to wood. Gribbles make burrows in submerged wood which resemble termite burrows. The wood is attacked at the surface and the animal digs down, then proceeds to tunnel parallel to the surface wood and just below the surface. This weakens the outer layers of wood and these layers break away. The gribbles then dig deeper into the wood gradually eroding it away from outside so that a wooden piling eventually assumes an hour-glass shape in the region of attack. Often thousands of gribbles can be found attacking a single pile in a narrow zone in the low intertidal area.

Gribbles bore into wood by means of a pair of stout mouth parts (mandibles). The right mandible has a sharp hook on it that tears at the wood at the blind end of the tunnel; the left one has a rasp-like groove into which the right mandible fits, so that loosened wood splinters can be rasped into smaller fragments and swallowed. Gribbles are very efficient in digesting wood and derive most of their nourishment from the wood they bore into.

As both shipworms and gribbles rasp away the wood as they excavate their tunnels they produce sounds as they bore. Several investigators have reported listening with a stethoscope to the sounds made by wood borers, but there appears to be no published account of these sounds being recorded and analyzed. The stimulus for the present investigation was the idea that perhaps shipworms and gribbles make sounds while boring that are unique in spectral quality. If this were true, one could record sounds coming from a wooden waterfront structure and perhaps determine if wood borers were present and the intensity of infestation which would give some measure of damage to the wood. We realized early that the major problem would be in filtering out all the backgound noise created by the numerous fouling organisms on the pilings, but we hoped it would be possible to recognize the sounds of boreres even with a background of noises made by barnacles and other foulers.

Area of Study

This investigation involved both field and laboratory aspects. The primary study site was in Monterey harbor where several wharves exist which are supported by wooden pilings. The marina which is part of the harbor is enclosed by wooden bulkheads. All of these wooden structures eventually are attacked by marine wood borers and these borers and the damage they cause have been investigated intensively during the past 10 years by students and staff of the Naval Postgraduate School. Pilings are regularly replaced in the harbor as the older ones become weakened due to the activity of borers. We were able, therefore, to study pilings recently placed in the water and not infested with borers and compar these with pilings that had been in the water 20 years or more and were carrying heavy infestations of borers. In addition, experimental panels of wood were exposed in racks at various depths in the harbor in order to collect wood borers for laboratory study. Laboratory studies were carried out at our beach laboratory which is near Monterey harbor and where running sea water is available for keeping borers alive in their wooden burrows for extended periods of time.

Methods and Equipment

A critical step in this investigation was to record natural sounds of shipworms and gribbles in wood uncontaminated with other outside sounds. From these recorded sounds spectral analyses could be made. It was therefore essential to be able to isolate shipworms and gribbles from one another and from other possible sources of biological sounds such as living barnacles on the surface of the wood. Gribbles settle on wooden surfaces in Monterey harbor throughout the year, but the shipworms spawn and settle on wood in numbers only during the winter months when the water is cold (Haderlie & Mellor, 1973). To collect pure populations of shipworms, therefore, it was necessary to expose experimental wooden panels during January and February. Gribbles were collected on experimental surfaces later during March and April.

What was needed for laboratory study was an experimental panel of wood large enough to successfully collect borers in nature and allow them to grow to full mature size, but small enough to be handled conveniently for x-ray analysis and for keeping in aquaria. It was essential, however, to have only shipworms or gribbles infesting any one panel, and the panel should be entirely free of any fouling growth such as barnacles when brought to the laboratory for study and sound analysis.

In studies over the past several years we have employed standard Douglas fir panels 30 cm long, 15 cm wide, and 2 cm thick, and such panels were used successfully in this study. The panels were exposed in sterile sea water for

10 days until they became water-soaked, then they were wrapped snugly with wide Scotch #490 (Saran) tape. This tape covered all parts of the panel except for the ends (in the case of experimental shipworm panels) or a small patch of the flat surface (in the case of panels designed to collect gribbles). These panels were then deployed in stainless steel racks and suspended in the water under Monterey Municipal Wharf No. 2. Racks with panels designed to collect gribbles were suspended just below the low tides level; those designed to collect shipworms were placed just above the bottom in 10 m of water where experience had shown shipworm settlement to be most intense.

Panels exposed in January and February 1979 successfully collected populations of shipworms (Bankia setacea). Invasion of the panels was determined by removing panels at periodic intervals and x-raying them to see if shipworms were present. By May and June 1979 the shipworms were nearly mature size in burrows up to 30 cm long. Figs. 1, 2, and 3 are x-rays taken after 2, 4, and 6 months of exposure. The panels were then brought to the laboratory for recording sessions. The plastic Saran wrap was removed, which was by 6 months covered with fouling growth, leaving a clean unfouled panel. Any barnacles on the panel ends were carefully removed so that we had a panel free of any gross fouling but infested with mature shipworms. These were then kept in running sea water aquaria.

The panels designed to collect gribbles (Limnoria quadripunctata) were infested as soon as the panels were exposed to the water in March and April, but by this time no shipworm larvae were present in the water and we had panels with sizable population of gribbles but free of shipworms. These panels too were kept in laboratory aquaria after the plastic wrap and fouling growth had been removed.

Fig. 1

X-ray photograph of 15 x 30 cm fir panel submerged 2 months in Monterey harbor showing small shipworms (Bankia setacea) in their burrows

Fig. 2

X-ray photograph of 15 x 30 cm fir panel submerged 4 months in Monterey harbor showing intermediate sized shipworms (Bankia setacea) in burrows

Fig. 3

X-ray photograph of 15 x 30 cm fir panel submerged 6 months in Monterey harbor showing mature shipworms (Bankia setacea) in their burrows

After panels had been in laboratory aquaria for a day or two, observations with a microscope showed that the shipworms had their siphons out and were actively circulating water, and the gribbles were observed starting new burrows or extending old ones. So we had a living population of each type of borer in separate wooden panels and could make recordings of their sonic signatures while boring.

When making recordings an isolated panel would be placed in a large container of sea water at ambient temperature, but circulation of water through the container would be cut off to remove one source of outside noise. The container housing the panel was placed on a stack of insulating tiles and foam rubber and all fluorescent lights were turned off so that their ballasts would not add outside interference. While recording the laboratory was very quiet.

A variety of types of hydrophones, pre-amplifiers, amplifiers, boosters and recorders were tried. Best results were obtained using an underwater microphone developed by Sound Wave Systems (Costa Mesa, California), a Panasonic RQ-212DKS cassette recorder, and volume-controlled Koss K-6LC headphones. This equipment was used successfully by Kitting (1979) in recording mollusc feeding sounds and was used for all recordings in this investigation.

Once an infested panel was placed in the chamber for recording, the microphone was placed near the terminal end of a shipworm tunnel (as determined by an x-ray of the panel made just before the recording session), time was allowed for the animals to extend their siphons so one could see wood chips emerging, then the recorder was turned on and tapes up to 60 minutes long made of the sounds. In order to correlate actual rasping sounds heard, a special technique developed by Miller (1924, 1926) was employed. By directing a powerful microscope lamp up through the bottom of a water-soaked panel one can, but observing from above with a low power stereomicroscope, see the shadow of the valves as they rock back and forth. By making such observations while listening with headphones to sounds being made, we could ascertain that specific sounds were associated with the boring activities of the shipworms.

Much the same technique was used when listening to and recording sounds from gribbles. So many gribbles were present in the panels, however, and they seemed to be eating the wood continuously, that it was difficult to get an isolated recording of one rasp stroke by one animal.

After we had recordings of the isolated sounds of shipworms and gribbles in experimental panels, we then recorded sounds coming from pilings in place in the harbor. To do this we used microphones with long leads and while diving attached the microphones firmly to pilings at levels from the intertidal zone to the bottom. We put some microphones on pilings that were old and suspected of harboring large populations of borers; other microphones were placed on pilings that were only a few months old and carried a sizable fouling growth but perhaps no borers, for the cresote was still fresh in the pile. Recordings of sounds eminating from these *in situ* pilings were made for comparison with the recordings from experimental panels.

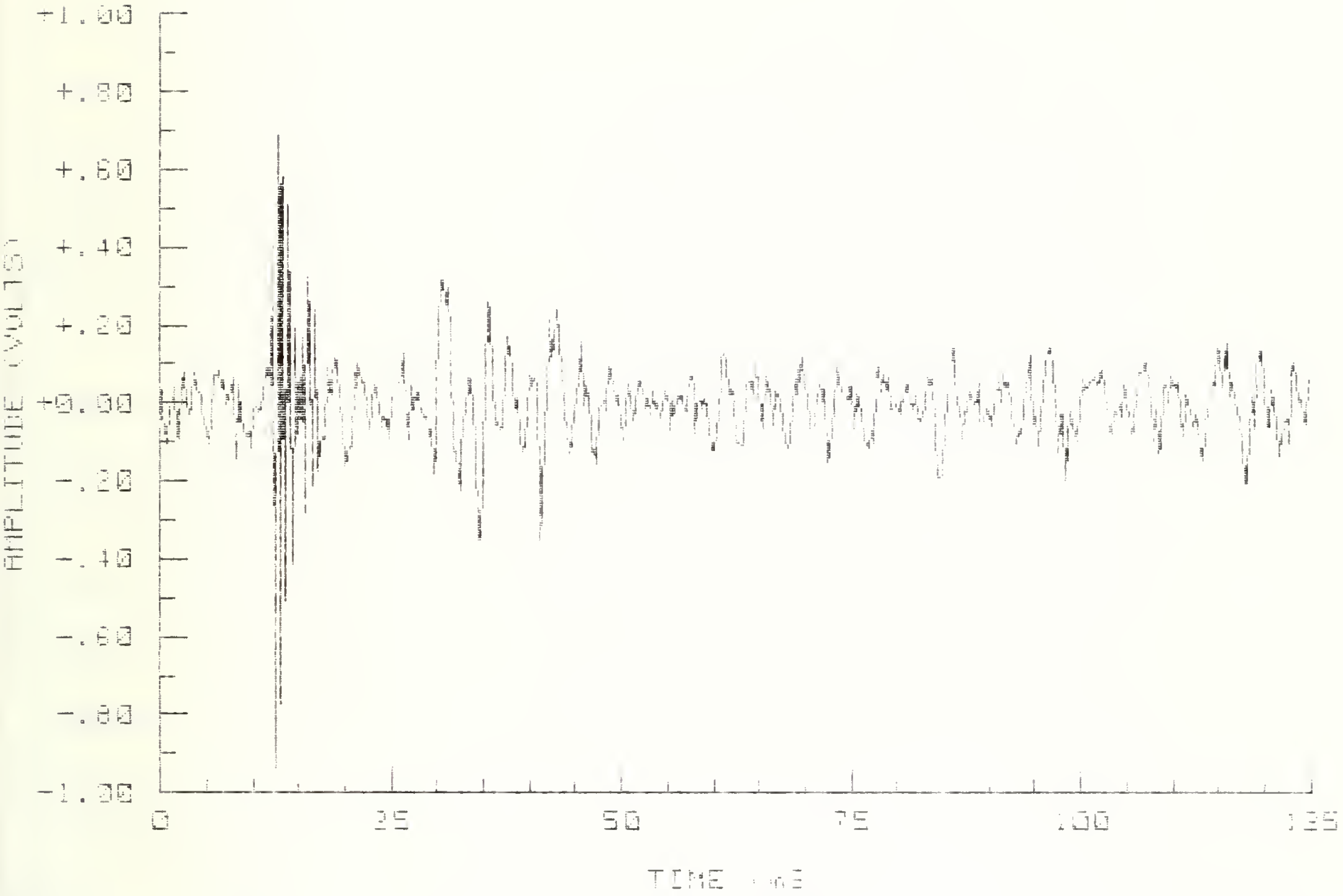
The recorded tapes were analyzed and graphic displays of the sonograms were made using a Hewlett Packard 3582A spectrum analyzer and an H.P.9845A computer for hard copy readout.

Results

Records in the literature have many references to sounds made by shipworms as they bore into wood. Kofoid (1921), for example, said: "When the borers are active in a piling it is possible to hear the rasping of their tools on the wood by placing the ear against the exposed top of the pile." We have been unable to repeat these observations in Monterey harbor. Piles with an infestation of shipworms also normally carry a heavy fouling growth of barnacles and the feeding sounds coming from the barnacles masks any sounds coming from within the piles. Experimental panels known to be infested with shipworms give no evidence of such infestation to the unaided ear. Neither does the use of a medical stethoscope detect borer sounds. When a microphone, amplifier, and headphones are used, however, one can easily hear the animals as they bore into the wood, and by using techniques described above one can visually see the action of the shell valves of shipworms that create the sounds.

The surprising feature of the sounds is their low intensity. One would expect that when a file-like shell is pressed against wood and rasped firmly enough to remove wood fibers that a fairly loud sound would be produced, but this not the case. Visual observation and sound records of individual shipworms made during this investigation show that between each rasping stroke the animal withdraws the shell from against the wood and allows water to cover the blind end of the tunnel. After an interval of several seconds, or occasionally minutes, the shell valves are then brought up against the wood for a new rasping stroke. It is postulated that the water soaks the wood at the blind end of the tunnel so that between rasping strokes the wood fibers are softened, and when the valves are brought against the wood they scrape away these softened fibers producing a sound of low intensity. The sound one hears, therefore, is quite faint but distinctive.

We have made many graphic recordings of these shipworm sounds, some of them of long duration showing a complete cycle from one rasping sound to another. All of these recordings show similar characteristics and an example of the critical part of the time record of _Bankia setacea_ boring into an experimental fir panel is shown in Fig. 4. The characteristic feature of all sonograms is a long interval between rasping strokes when no sound is heard (not shown in Fig. 4). As the animal maneuvers the shell valves into position a faint sound is heard (left part of Fig. 4), then as the valves contact the wood a sharp click of very



CHA TIME RECORD FOR RASPING OF BANKIA IN EXPERIMENTAL PANEL

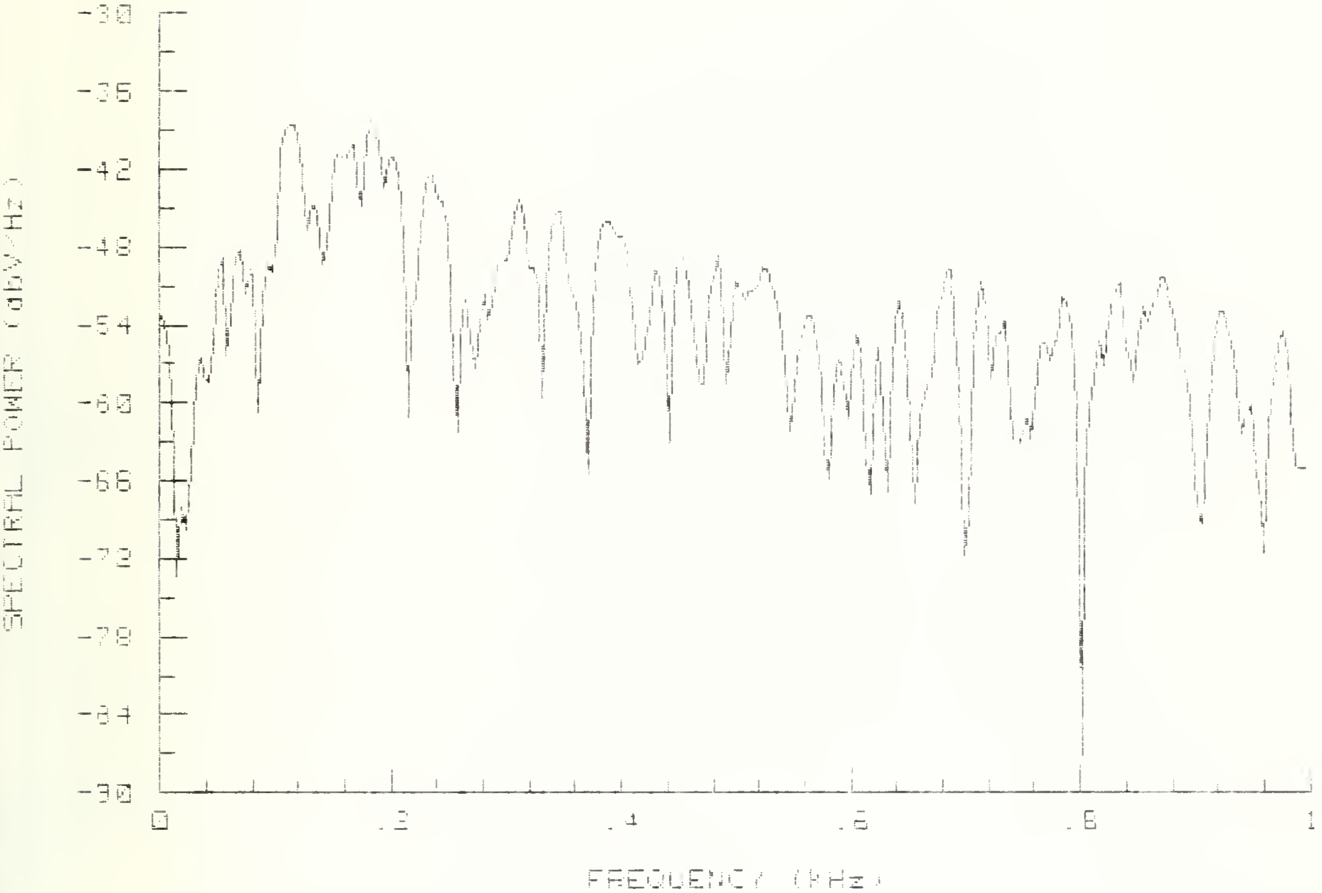
Fig. 4

short duration is produced. This is followed by sounds of less intensity as the shell is pulled away from the wood. These latter sounds last from 1 to 2 seconds then no sound is heard until preparation for the next rasping stroke.

Fig. 5 is a graphic display of the sound spectrum of the rasping sound recorded in Fig. 4. It should be pointed out that the spectrum shown in Fig. 5 is an analysis of the entire 125 mS record shown in Fig. 4. Fig. 5 (as well as Figs. 7 and 9 which follow) show spectra only up to 1 kHz. We recorded higher frequency spectra up to 20 Hz in each case, but these spectra gave no additional significant information.

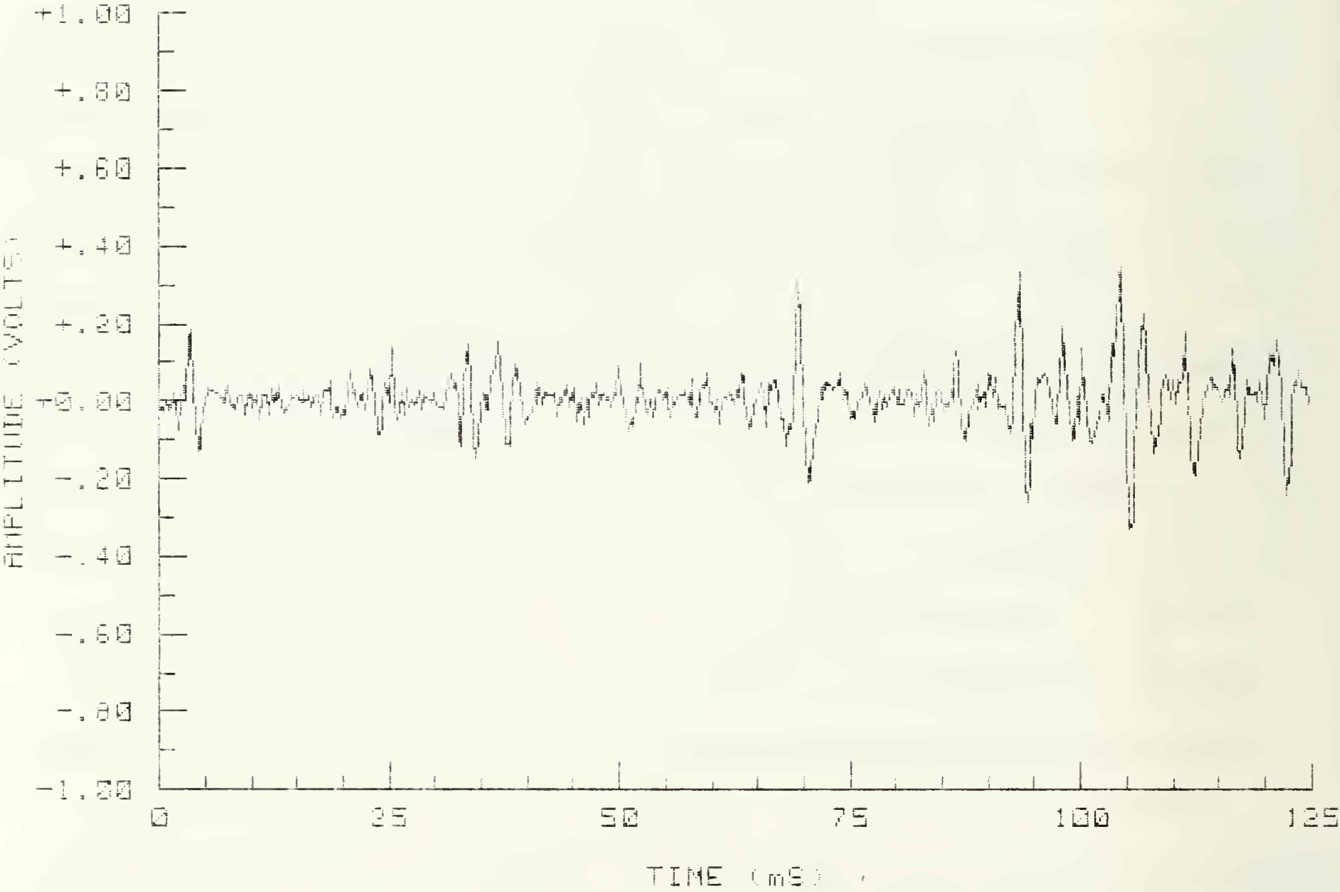
The sounds produced by the gribble *Limnoria quadripunctata* in experimental fir panels are more continuous and less distinctive than the shipworm sounds described above. It is impossible to isolate one gribble in a burrow and record its feeding sounds, so all of our records are of small populations of gribbles feeding near where the microphone is placed on the wood. It is not surprising, then, that continuous rasping sounds of low intensity are recorded from such infested panels. Fig. 6 is a short fragment of one of the long time records we have made. These sounds go on continuously. Fig. 7 is a spectral analysis of the time record shown in Fig. 6 and shows that the spectrum of *Limnori* sounds is similar to but slightly lower in spectral power (dbV/Hz) than that for *Bankia*.

The fundamental objective of this investigation was to determine if it were possible to detect shipworms and/or gribbles in wooden harbor structures which had been in the water for some time. Sound recordings were therefore made from a variety of different wooden pilings of various ages (in terms of time in place) and at various depths from the intertidal zone to the bottom. For comparative purposes sounds were also recorded from newly placed wooden pilings and from old fouling encrusted concrete pilings.



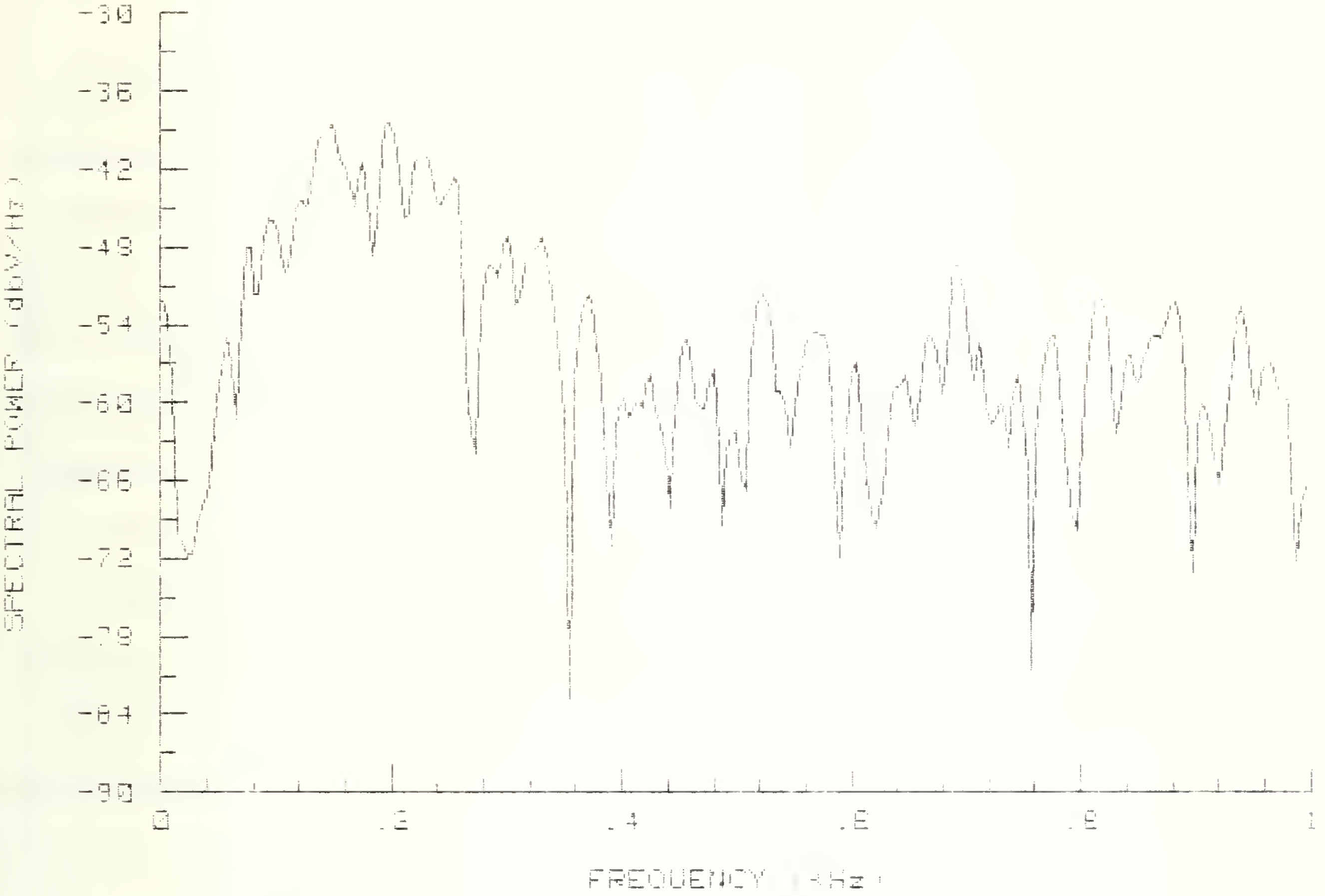
CHA SPECTRUM FOR RASPING OF BANKIA IN EXPERIMENTAL PANEL

Fig. 5



CHA TIME RECORD FOR RASPING OF LIMNORIA IN EXPERIMENTAL PANE

Fig. 6



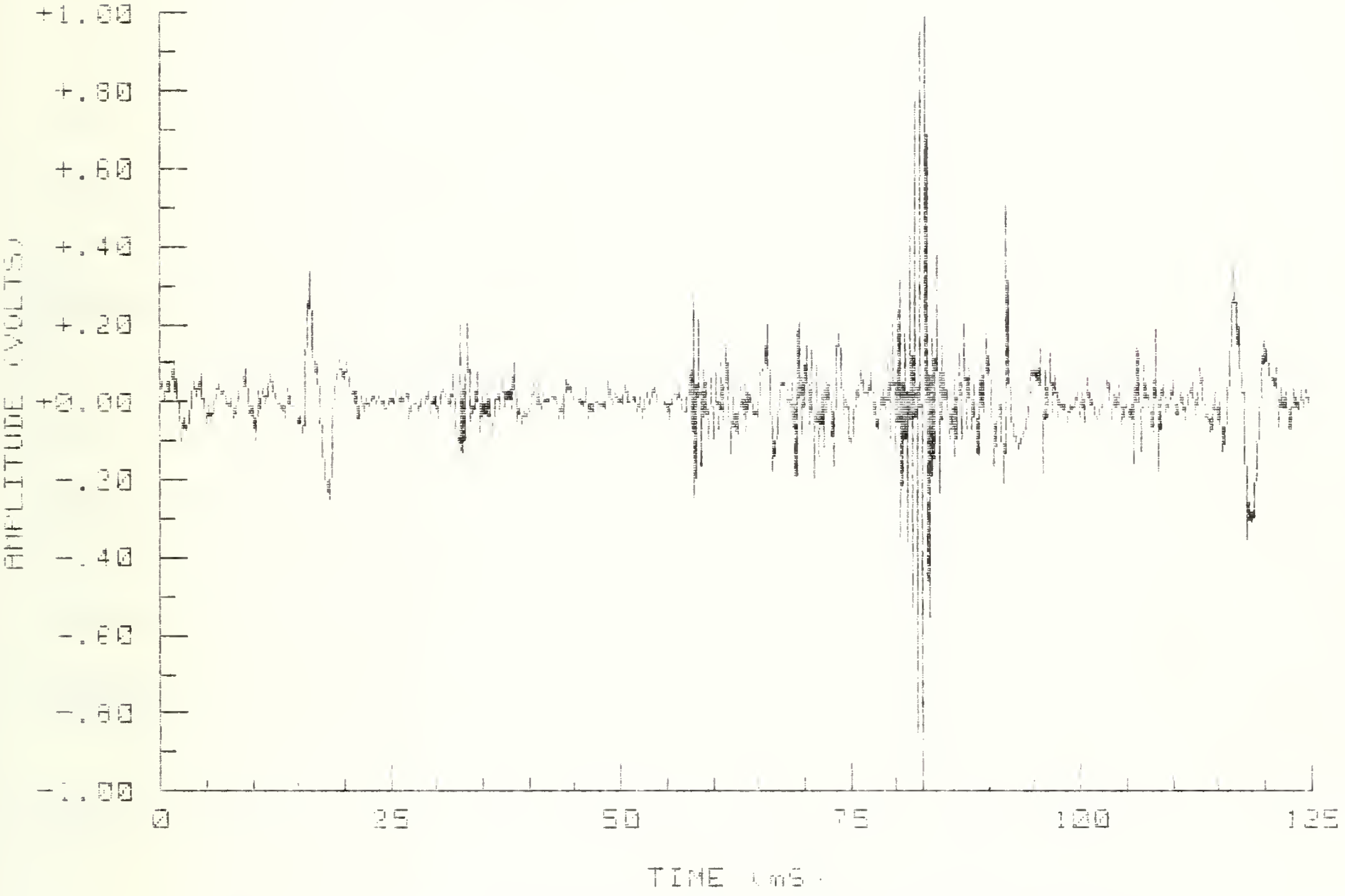
CHA SPECTRUM FOR RASPING OF LIMNORIA IN EXPERIMENTAL PANEL

Fig.7

For newly placed pilings the only sounds detected were those suspected of coming from animals in the water nearby. On all others the microphones picked up a vast variety of sounds coming from the surface and sometimes presumably from the interior of the piling. Dozens of such recordings have been made, and they are all different from one another.

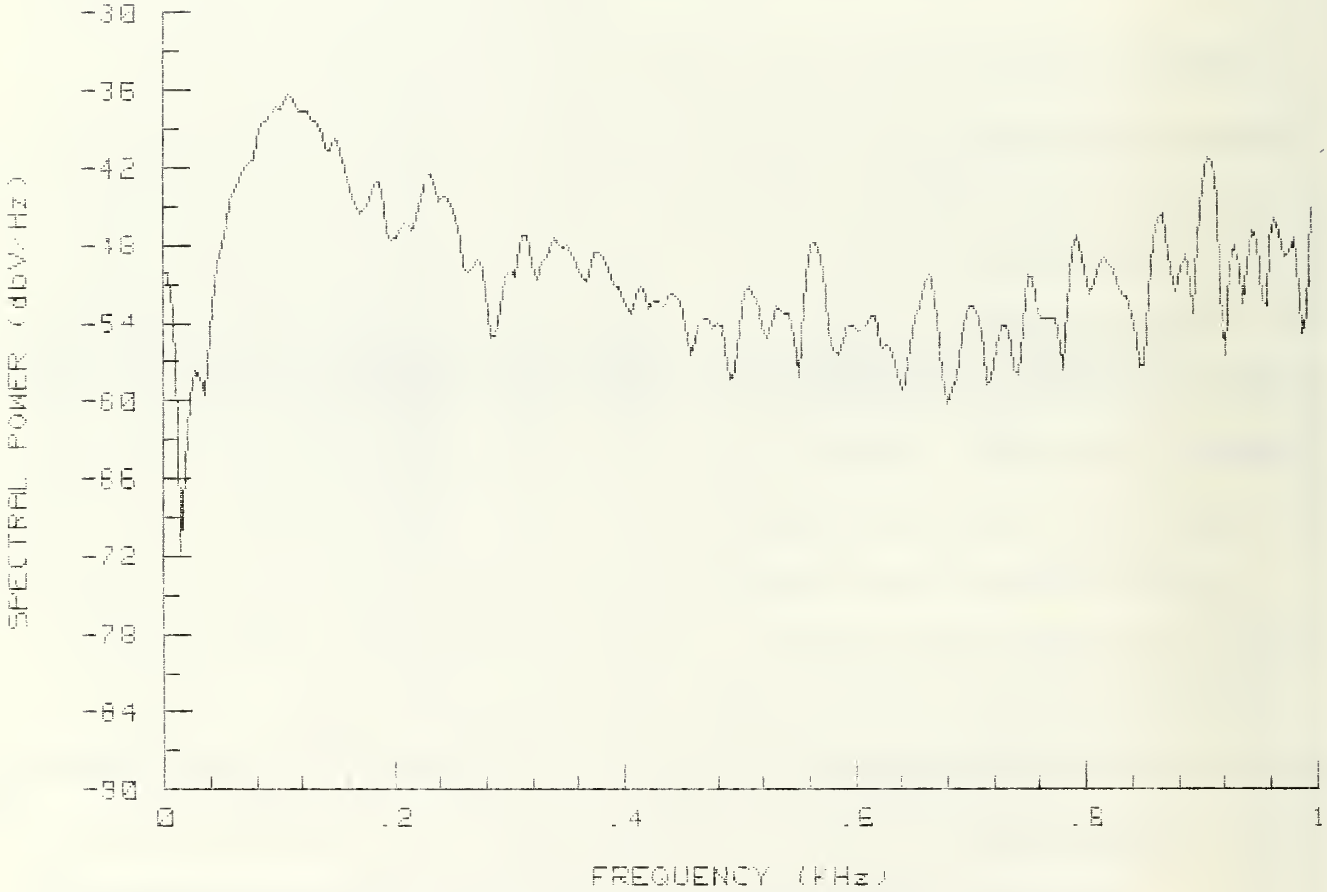
In order to attempt to visualize which of the visible fouling organisms were responsible for producing some of the sounds heard, a microphone was placed on an old wooden piling 1 m below low tide level, then a diver with headphones in the helmet observed barnacle activity in the vicinity of the microphone while listening to the sounds being picked up. Two species of barnacles encrusted the piling: masses of the small acorn barnacle Balanus crenatus coated the surface and one large Balanus nubilus was next to the microphone. Fig. 8 is a fragment of a long time record made. Most of the low amplitude sounds in the record probably came from the clicking sounds as the small acorn barnacles opened and closed their shell plates in feeding. To the ear this sounds like continuous static and it ceases if the diver wipes a hand over the barnacles which causes them to stop feeding momentarily. In Fig. 4 the sound recorded at 85 mS was presumably from the shell plates closing on the large barnacle Balanus nubilus. Fig. 9 is a spectrum record of the time recording illustrated in Fig 8.

The sonograms and spectral nature of the sounds recorded from natural harbor structures varied greatly, but the records shown in Figs. 8 and 9 are typical. Unfortunately, it has proved to be impossible, as far as our records are concerned, to analyze the sonograms made of natural sounds eminating from pilings and from this determine if boring animals are contributing to the sounds. We have discovered no method in these analyses for filtering out the ambient noise of foulers on a pile, especially the continuous sounds of feeding barnacles. We have made comparisons between sonograms from old wooden pilings known to be infested with shipworms with those from concrete pilings carrying a similar fouling growth and we cannot distinguish between the sonograms.



CHA TIME RECORD FOR NATURAL SOUNDS FROM WOODEN PILING

Fig. 8



CHA SPECTRUM FOR NATURAL SOUNDS FROM WOODEN PILING

Fig. 9

Conclusions

Our conclusions from these studies can be stated quite briefly. It is possible to record the rather faint sounds associated with boring activities of shipworms and gribbles as they tunnel into experimental wooden panels, and all other sounds can be excluded from the recordings. It is also possible to record the sounds coming from in-place wooden pilings in a harbor. Sonograms and spectral analyses of these sounds can be made. However, even with a clear time recording and spectral analysis of sounds made by a borer while isolated, we have been unable to determine if borers are present in a piling in the harbor by using passive listening techniques. The reason for this failure is that the natural sounds of barnacles and other foulers on a piling are so diverse and complicated that they mask any borer sounds coming from within the piling and we have been unable to filter out the extraneous sounds which might make it possible to detect borers in a wooden harbor structure.

Recommendations

It is possible that active sonic scanning of wooden harbor structures could give useful information on damage due to wood borers. We have experimented with currently available medical instruments used for acoustic holography of the human body which detect tumors, gallstones, etc., but find that the wood is too dense to achieve much penetration. If acoustic holography instruments in the 25-50 kHz range were available, useful holograms of wooden harbor structures might be made.

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